Preparing for GOES-R and JPSS: New Tropical Cyclone Tools Based on 30 Years of Continuous GOES IR Imagery

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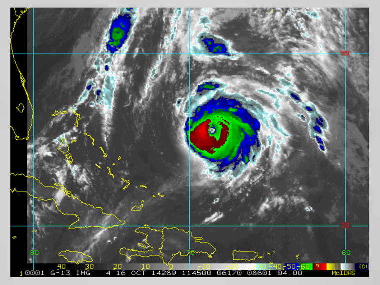
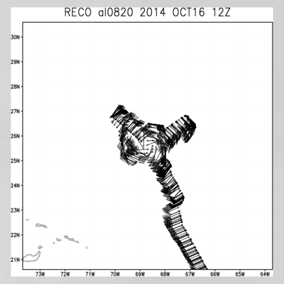
Scientific Premise: As JPSS/SNPP and GOES-R platforms become available, the focus of the satellite community's funding, research, and product development often gravitates toward their new capabilities. This is sometimes justified, especially when the information content of older datasets has been exhausted. However this is sometimes not the case.

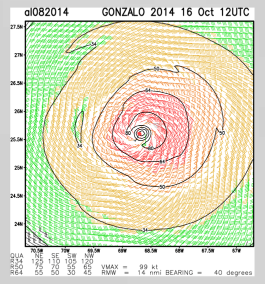
Here we argue that tropical cyclone (TC) research and product development is a case where there is untapped potential in the information contained in older satellite data. The reasons are many. The observation of tropical cyclones has dramatically improved in the last 20 years. Some significant observational improvements are based on satellite platforms (e.g., scatterometry, microwave imagery, water vapor imagery) while others (e.g., aircraft reconnaissance instrumentation, improved dropwindsondes) are not. Statistical techniques, data storage, data availability, and computational speed have also all improved. In sum, the availability of improved observations, analysis techniques, computing, and physical understanding of TCs has improved so much that new capabilities can be developed using older geostationary and polar data.

Data Available for TC Application Development

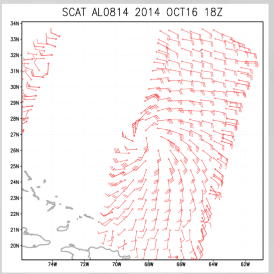


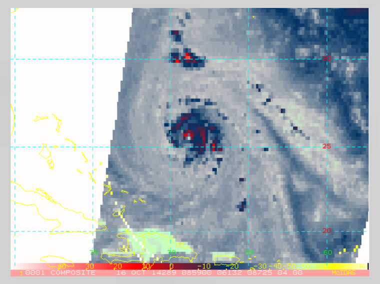
- **IR Imagery**
  - CIRA/RAMMB TC IR Image Archive (1990-pres)
  - HURSAT (1978-2009)
- **TC Information**
  - ATCF (Best tracks w/ wind radii, fixes, guidance, real time)
  - HURDAT2 (Best tracks w/ wind radii)
  - IBTrACS (all agencies)



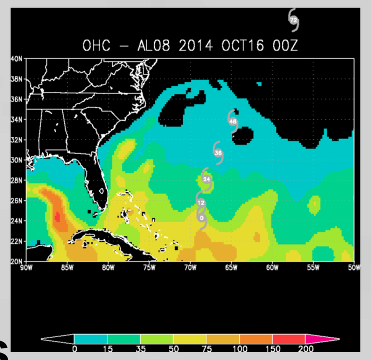


- **Aircraft Reconnaissance**
  - Air Force/NOAA (10 & 1 Hz; 1995-pres)
  - HDOBS (real-time access)
  - Dropwindsondes (real-time access)





- **Other Satellite**
  - Passive Microwave Imagery/Sounder
  - Scatterometry
  - CloudSat
- **Ocean Analyses**
  - Navy Coupled Ocean Data Assimilation (NCODA)
  - NESDIS operational products



- **Model analysis/forecasts (HWRF/GFS)**
  - Fields
  - Synthetic Imagery

Potential Forecast/Diagnostic Applications

- **Surface wind structure**
  - TC size (vortex size as inferred from outer winds)
  - Diagnoses of the 2-D wind field using imagery and intensity
  - Relating TC size and intensity to wind radii
  - Statistical-dynamical wind radii prediction
- **Eye/radius of maximum winds**
  - Objective eye detection and/or probability of existence
  - Forecasting eye development/eye diameter
- **Intensity**
  - Rapid Intensification Forecasts (probabilistic)
  - Statistical Dynamical Forecasts (deterministic)

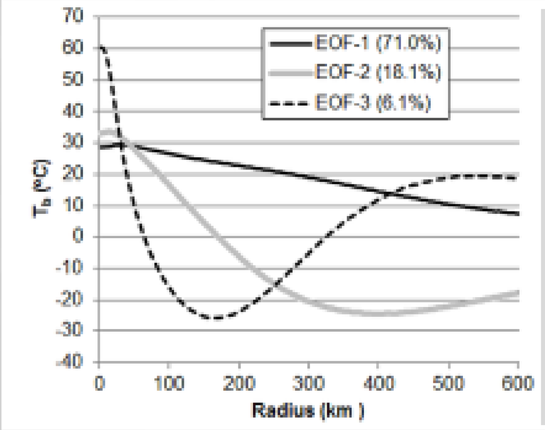
Example Applications Developed with These Data

IR-based TC Size Estimates (Knaff et al. 2014)

- Based on the 1D (azimuthally average) Principle components and latitude (no intensity)

$$V500 = 2.488 + 11.478*\sin|\varphi| - 1.350*PC1 + 0.912*PC2 + 0.319*PC3$$

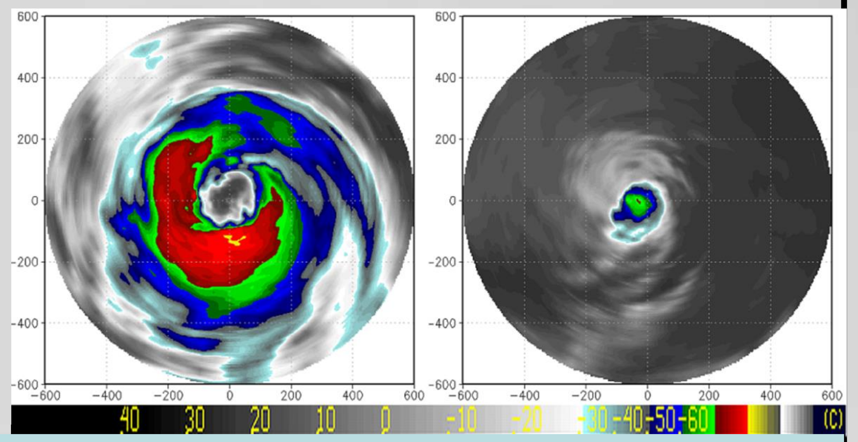
$$R5 = (R5 + (V500 - V500c)*500/(V500c - V1000c))$$



V500 is the tangential wind at 500 km radius.

Satellite & Lat. information is trained on model analyses

Leading modes of variability or Empirical Orthogonal Functions (EOFs) of the 6-hourly mean azimuthally averaged profiles of IR BT. The percent of the variance explained by each EOF is shown in parentheses.



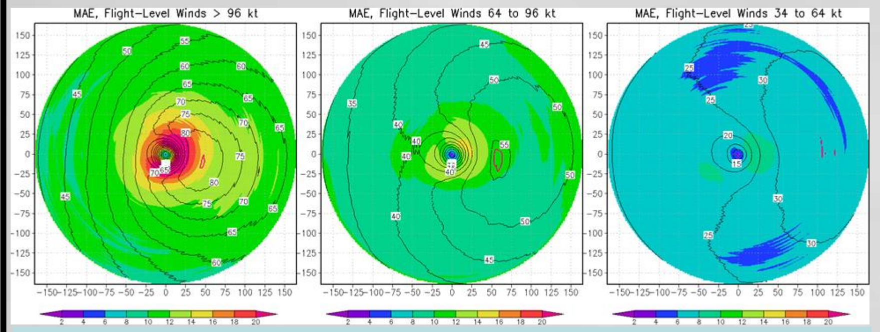
IR images of Typhoon Abe (left, 25.2°N, 124.8°E, 90 kt, 30 Aug 1990, 00 UTC) and Hurricane Kay (right,16.0°N, 123.8°W, 65 kt on 13 Oct 1998 18 UTC). These images also had PC1 values of -1.1 and 1.0, PC2 values of 2.8 and -2.3 and PC3 values of 2.1 and -2.6 for Abe and Kay, respectively. These are the largest and smallest hurricanes in a 30-yr global dataset.

Additional Applications Derived from TC Size estimates

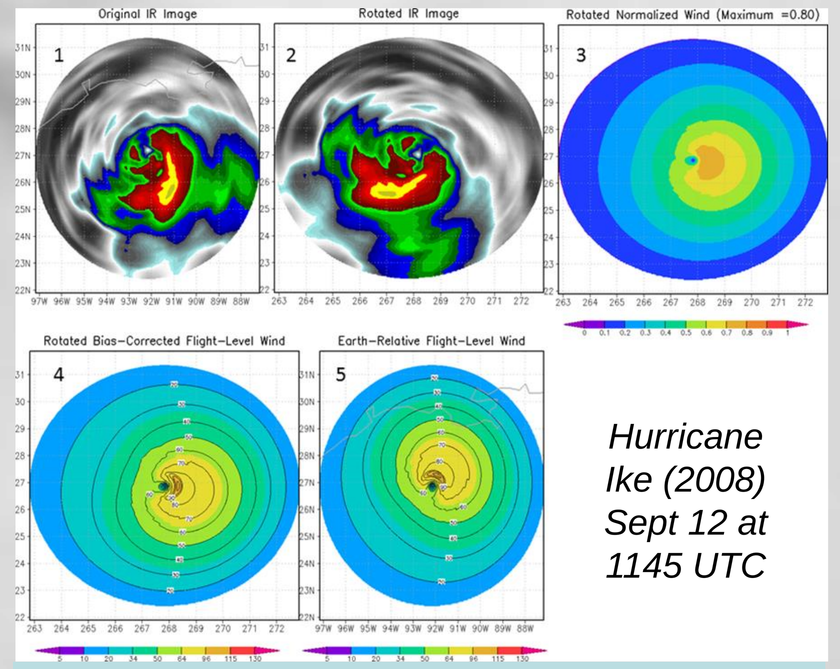
Application	Use
1. Wind Radii given intensity, motion vector and TC size	Can be applied to intensity fix(es) (e.g. Dvorak) Provides a distribution for Monti-Carlo/stochastically generated storms for climate risk modeling
2. TC size as the basis for statistical-dynamical size/wind radii forecasts	Can potential provide wind radii estimates consistent with SHIPS/LGEM
3. TC size can be used to scale observational data	Any application requiring size normalization for average quantities(e.g., rainfall, core/rainband separation, lightning)
4. Model diagnosis	Can quantify sizes from synthetic imagery, assess TC growth etc.

2-D wind field (Knaff et al. 2015)

- Based on intensity estimate, 2-D storm relative IR principle components
- Trained on aircraft-based flight-level data decomposed into azimuthal wavenumbers 0-1 and their phases
- Produces an estimate of the 2-D wind field
- Uses a method called single field principle component analysis that relates wind amplitudes and phases to the IR principle components.



Dependent mean wind field (contours) and absolute errors (MAE, shaded) stratified by flight-level analysis winds with cases with winds greater than 96 kt (left), winds 64 to 95 kt (middle) and winds 34 to 64 kt (right). Note motion is toward the top of the page. The magenta contour on each panel shows where the average RMW of flight-level wind is located in each composite. The scale is the same for all figures.

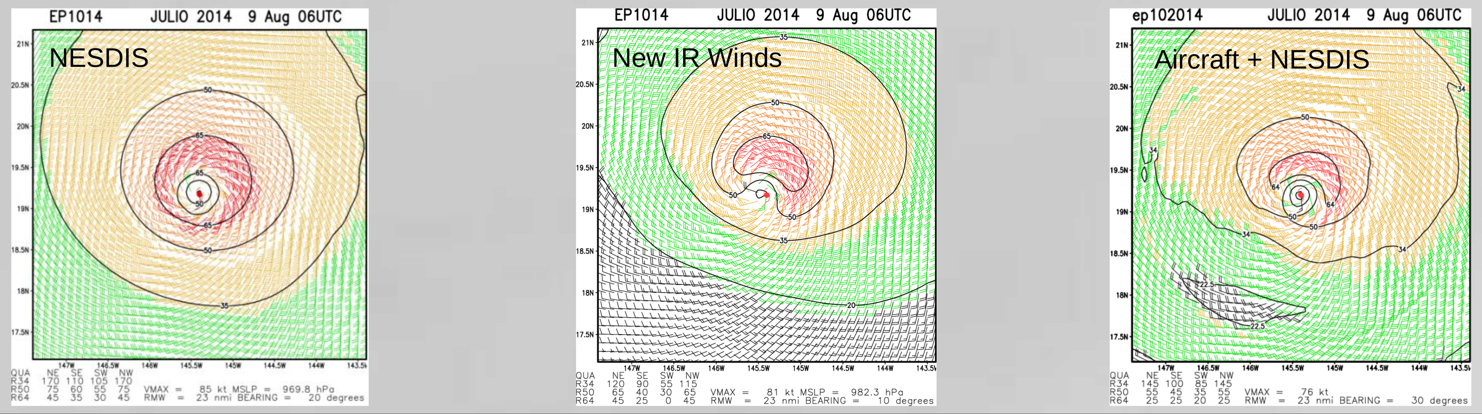


Hurricane Ike (2008) Sept 12 at 1145 UTC

An illustration of the steps taken to estimate the wind field. Imagery are mapped to a polar grid (1) and then rotated with respect to direction (2). Rotated imagery, translation speed, latitude and intensity are used to estimate the normalized wind field (3). The observed intensity is then applied to create a wind speed field (4). Finally the wind field is rotated back to its earth-relative directional component (5).

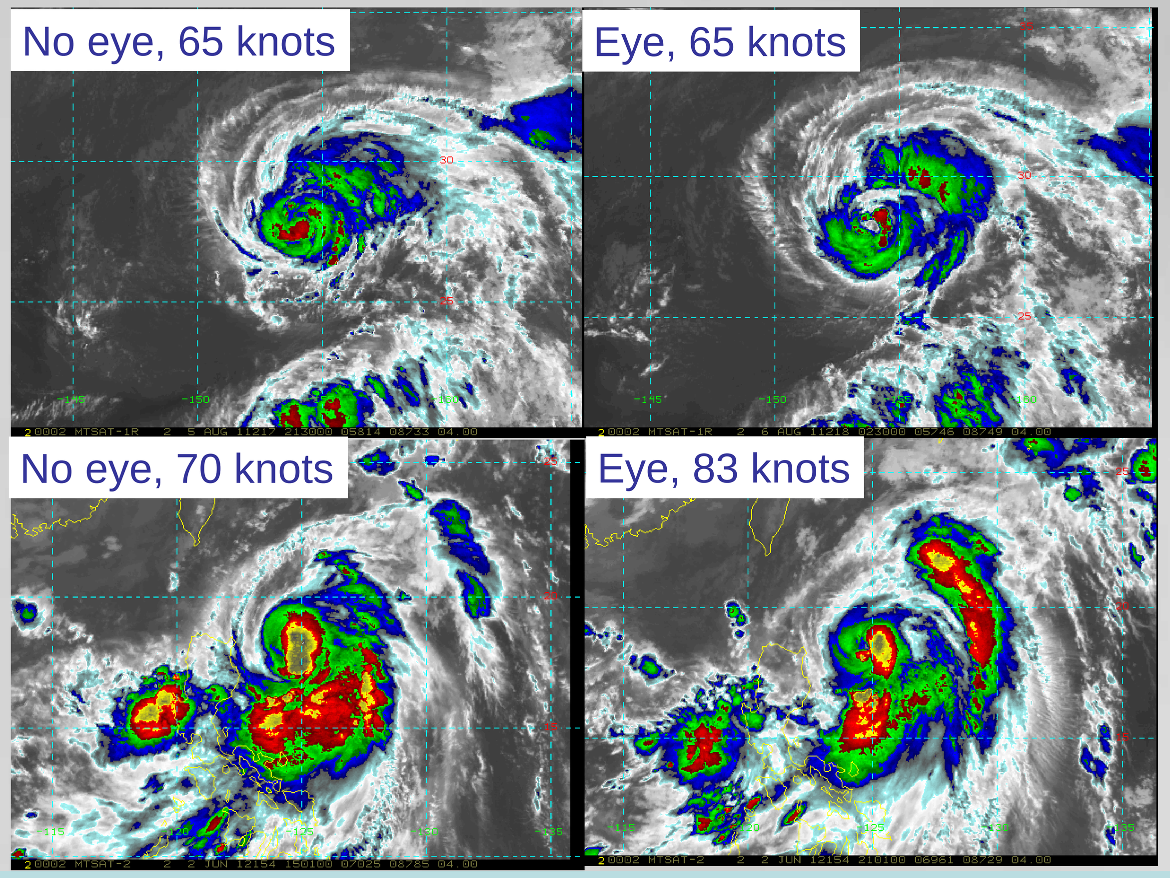
Additional Applications Derived from 2-D Wind Fields

Application	Use
1. NESDIS Multi-Platform Tropical Cyclone Surface Wind Analysis	Improve the inner core flight-level wind estimates
2. Vortex Data assimilation	Can be used to specify the wind distribution including RMW
3. Input for aircraft-based analyses.	First guess



Eye Detection/Eye Size/Radius of Maximum Wind

- Dvorak fixes (ATCF) are used to develop eye no-eye training set (n=2677) based on six-hourly Atlantic and East Pacific tropical cyclones.
- Machine learning algorithms used to train an objective eye detection scheme (under JPSS funding, see Robert DeMaria's poster)
- Preliminary results suggest that this scheme can detect 75% of the eye cases with false detections of ~20% when using a 50 knot intensity threshold



Two West Pacific cases, WP122011 MERBOK (top, 65 knots) and WP042012 MAWAR (bottom, 70-83 knots). Images on the left show the no-eye image 6 hours prior to the images on the right which were subjectively determined to have an eye.

Next Steps

- Refine algorithm with different intensity thresholds/data subsets
- Develop probabilistic eye/no-eye algorithm
- Run the algorithm on all images in the CIRA/RAMMB TC archive (~500,000 unique times)

Additional Applications Eye Detection/Eye Size/Radius of Maximum winds

Application	Use
1. Intensity forecasting	The probability of eye formation provides vital information as to the short-term intensification rate
2. Climatology of eye size, eye formation	Detailed climatology of eye size and eye formation is of general interest. Eye diameter is related to RMW
3. Eye anticipation, eye size product	This would aid short-term forecasts and forecasters
4. Model diagnosis	Methods could compare model eye formation to climatological aspects of eye formation (2)

Summary

The increased availability of improved observations, new analysis techniques, computing efficiency, and physical understanding of TCs has improved so much that new capabilities can be developed using older geostationary and polar data. Such capabilities can easily be transitioned to future operational and analysis techniques that make use of JPSS and GOES-R imagery and products.
Work to develop new tropical cyclone capabilities using legacy GOES and POES imagery will continue at CIRA/RAMMB and is the basis for much of our GOES-R product development effort.

References:

Knaff, J.A., S.P. Longmore, D.A. Molenar, 2014: An Objective Satellite-Based Tropical Cyclone Size Climatology. *J. Climate*, **27**, 455-476.
Knaff, J.A., S.P. Longmore, R.T DeMaria, D.A. Molenar, 2015: Improved tropical cyclone flight-level wind estimates using routine infrared satellite reconnaissance. Accepted to *J. App. Meteor. Climate.*
DeMaria, R.T., G. Chirokova, J. A. Knaff, and J. F. Dostalek 2015: Machine Learning Algorithms for Tropical Cyclone Center Fixing and Eye Detection. 20th Conference on Satellite Meteorology and Oceanography.

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